Use of MCNPX for Alpha Spectrometry Simulations of a Continuous Air Monitor

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INTRODUCTION

The purpose of this study was to determine if the alpha energy spectrum in a Passive Implanted Planar Silicon (PIPS) detector, as modeled by MCNPX [1], can be used to design a radon stripping algorithm for a continuous air monitor (CAM). This stripping algorithm would be employed to discriminate naturally occurring radioisotopes from the anthropogenic for nuclear safety - related applications. It is hoped that using an algorithm based on MCNPX simulations, the CAM will not be prone to false alarms when radon levels are dynamic as identified in other CAM systems [2,3].

This work is focused on the design of the next generation air particulate detector (NGAPD) for the United States Navy. The primary isotope of interest is Co-60. This radionuclide emits a beta with an average energy of 96 keV. Therefore, once deposited on the CAM filter, it will produce a beta continuum seen by the PIPS detector. In addition, as radon progeny is deposited on the air filter, these will give rise to characteristic alpha peaks and a beta continuum. This is primarily an issue in port-or land-based applications. Ultimately, measurement of a radon alpha spectrum is desired to predict the amount of beta activity which would be measured from the radon progeny decay chains. All excess beta activity could then be attributed to anthropogenic sources once the radon progeny contributions have been stripped out.

PRELIMINARY PROTOTYPE PIPS DETECTOR

The configuration shown in Figure 1 utilized a standard Canberra CAM PIPS detector along with a PC104 stack multichannel analyzer and a commercial preamplifier board. The air flow system is basically an air pump with a filter holder such that the clamp assembly for the PIPS detector allowed placement of the detector within a millimeter or two from the surface of the filter paper.

MCNPX MODEL

The Monte Carlo code MCNPX version 26a5 was used for this work. The energy cutoff for alpha particle transport was set at 10 keV. The filter paper was modeled as celotex [4], at a density of 0.3 g/cm^3. The detector was modeled according to the manufacturer's specifications. Gaussian energy broadening [1] was utilized according to equation 1 using the *ad hoc* coefficients, c_1=0.06 MeV, c_2=0.002 MeV$^{1/2}$ and c_3=0.05 MeV^{-1} (where E is in MeV). This was not found to be a critical feature for this application but was included to model the full width at half maximum (FWHM) values specified by the PIPS manufacturer [5].

$$FWHM = c_1 + c_2\sqrt{E + c_3 \cdot E^2} \qquad (1)$$

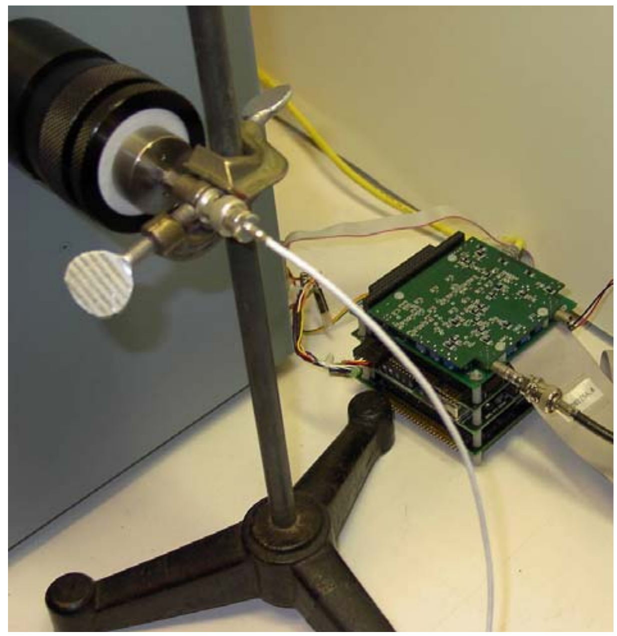


Fig. 1. Preliminary prototype electronics configuration of the NGAPD. In the upper left is the air sampling system and the PIPS detector mounted via clamps. The PC104 stack is shown in the center right of the figure.

An approximation was made for the source distribution within the filter material. In practice, the source should be distributed exponentially by depth. However, when using MCNPX for this configuration, this distribution was not modeled. To approximate this activity drop as a function of depth, a cubic in the form of x^{-3} was employed to a maximum depth of 88 µm. In other words, starting 88 µm in the filter, the source point density grew as x^3 approaching the surface of the filter. The radial distribution of the source material was uniform. Additionally, the source distribution was made to extend 12 µm beyond the surface of the filter paper to simulate the 40% unattenuated fraction described elsewhere [6]. (A large fraction of the aerosol deposits on the surface of the filter and does not penetrate, resulting in negligible filter attenuation on the alphas.)

The radon progeny was simulated using the distribution given in Table 1. Here it was assumed that the dominant progeny contribution was from Rn-222 with only about 2% from Thoron (Rn-220) and about 0.3% from Actinon (Rn-219). The values listed in Table 1 were selected to both give agreement with the measured spectrum, shown in Figure 2, and to credibly follow empirical distribution ranges given elsewhere [7]. The system air was modeled as normal dry air [8].

TABLE I. Radon Progeny Alpha Particle Distributions Assumed for MCNPX Simulation.

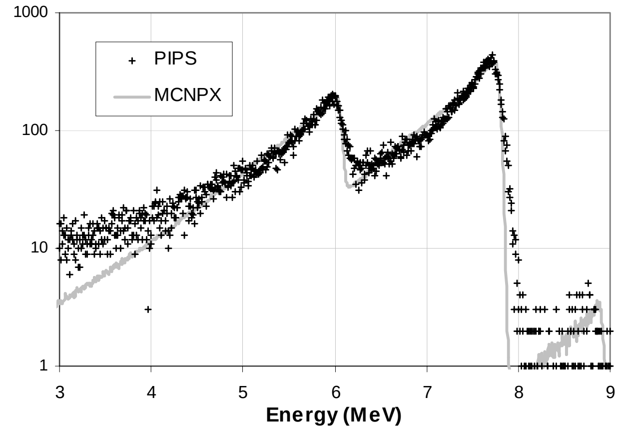
Isotope	Energy (MeV)	Fraction of total activity
Po-218	6.002	0.391
Po-214	7.687	0.583
Po-216	6.788	0.015
Bi-212	6.062	0.002
Po-212	8.785	0.004
Po-215	7.386	0.003
Bi-211	6.663	0.0017
Bi-211	6.278	0.0003

RESULTS

The experimental and simulation results shown in Figure 2 came from more than 9 hours of sampling. Excellent agreement is found between experimental and simulation values indicating that algorithms developed using the MCNPX spectra as templates would credibly represent the true physical phenomenon. Specifically, by implementing variations in Table 1 according to normal diurnal variations in radon and its progeny [3,6], the resultant MCNPX spectra could be used to represent algorithm inputs through simulation of multiple time increments.

DISCUSSION

When comparing the simulated and experimental results, it is noted that larger discrepancies occur in the low-energy tail of the spectrum. The probable reason for this difference is the treatment of the source distribution by depth as a function of x^{-3}. The actual deposition should be closer to an exponential resulting in a portion of the particulates being deposited deeper into the filter. This would cause a greater attenuation of the alpha energy for those deeply embedded source particles. Thus, the simulation would underestimate the number of lower-energy alpha particles registered by the PIPS (Figure 2). The resultant simulation is effectively a best fit of the simulation capabilities and the empirical results.



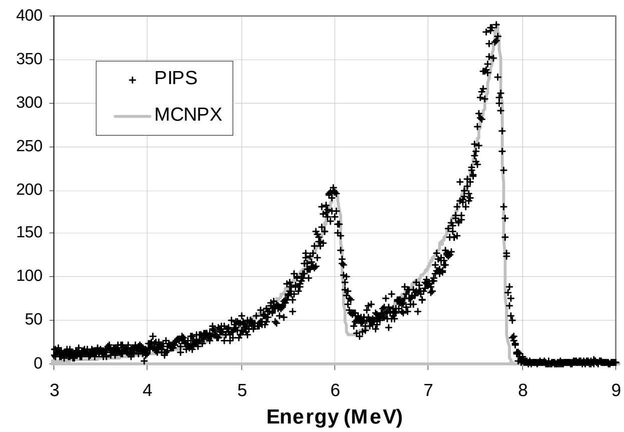


Fig 2. Superposition of measured and simulated alpha spectra for radon progeny. The upper image is a semi log plot of the same data shown in the lower image. Here, the lower image is intended to show the tail behavior more clearly.

CONCLUSIONS

The measured spectra from the preliminary prototype NGAPD can be adequately modeled by MCNPX for reliable algorithm development applications.

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